SEASONAL VARIATIONS OF SALTATION ACTIVITY ON A HIGH PLAINS SALINE PLAYA: YELLOW LAKE, TEXAS

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Abstract: The Southern High Plains region of West Texas and eastern New Mexico is often described as a flat elevated tableland. Spaced across this vast and otherwise featureless plain are 21 large closed basins containing approximately 40 irregularly shaped saline playas. Yellow Lake, located on the Yellow House Ranch northwest of Lubbock, Texas, is among the largest of the High Plains saline playas. This paper represents the first report of a 4-yr. study of saltation activity at Yellow Lake. From December 30, 1998, to January 1, 2003, a fast-response piezoelectric saltation sensor was used to collect a continuous record of aeolian activity at a point on the playa surface. Since saltation activity is often associated with dust emissions, the saltation record also provides information regarding seasonal patterns of dust emissions from the Yellow House Basin. Results suggest that blowing events can occur at any time of the year when conditions are favorable; however, the necessary conditions are rarely satisfied. As a result, the saltation record is characterized by many hours of inactivity punctuated with brief periods of occasionally intense aeolian activity. From December 30, 1998, to January 1, 2003, saltation activity was detected for only 7% of the hours measured. Although there can be substantial deviations from one year to the next, it was found that saltation activity tends to peak during winter months when winds are moderately strong and precipitation is at a minimum. Hourly saltation activity values occasionally approached unity during intense winter blowing events, indicating nearly continuous sediment transport over a one-hour period. Saltation activity is at a minimum during summer months when winds are often weak and wet conditions prevail. Although winds are typically strongest during the spring season, the playa is relatively stable due to high threshold values produced by significant spring precipitation. This contrasts sharply with the surrounding cropland, which tends to be most active during the spring season. [Key words: playa, deflation, saltation, aeolian, dust, Southern High Plains.]

INTRODUCTION

The term playa is often used to describe the flat-floored bottom of a closed basin that becomes at times a shallow lake (Blackwelder, 1931; Shaw and Thomas, 1989; Blank et al., 1999). On the Southern High Plains, there are two distinctly different types of playas—the small circular freshwater playas and the larger and more irregular saline playas (Reeves and Parry, 1969). Though both playa types appear to share many common features, the saline playas are not equivalent in either form or origin to the circular playas (Sabine and Holliday, 1995).

Circular playas lie on the Blackwater Draw formation well above the water table of the underlying Ogallala formation (Wood et al., 1992). Runoff that collects in the circular playas slowly drains to the underlying Ogallala aquifer, flushing away salts

Physical Geography, 2003, **24**, 1, pp. 61–76.

in the process (Osterkamp and Wood, 1987). As a freshwater playa dries out, plants take root and limit aeolian deflation (Haukos and Smith, 1997).

Saline playas, on the other hand, are in close contact with the saturated zone of the Ogallala aquifer, which limits drainage (Holliday et al., 1996). A salt-encrusted clay surface develops as surface runoff and groundwater discharge evaporates. High salinity levels prevent plant growth leaving the bare playa surface highly susceptible to aeolian deflation. During periods of aeolian activity, clay aggregates are dislodged and transported across the playa surface. Fine fractions become suspended and form dust plumes that may extend great distances. Coarse grains are deposited near the partially vegetated playa margins where they form clay dunes, also referred to as fringing dunes or lunettes (Bowler, 1968; Reeves and Parry, 1969; Bowler, 1973). During periods of heavy rain, some of the dune sediments wash back onto the playa surface where they eventually dry out and become source material for future aeolian transport. This process sets up a continuous cycle of aeolian deflation and transport of playa sediments to the fringing dunes and fluvial erosion and transport of dune sediments back to the playa surface.

The following report is based upon a 4-yr. investigation of active aeolian processes at Yellow Lake, one of two saline playas within the Yellow House Basin on the Yellow House Ranch 62 km northwest of Lubbock, Texas. From December 30, 1998, to January 1, 2003, a fast-response piezoelectric saltation sensor was used to record temporal variations of saltation activity at a point on the playa surface. Simultaneous measurements of basic climate data were also obtained at the same point. In addition, a water-level sensor was installed near the deepest part of the lake to monitor the depth of standing water. This paper summarizes the measured data and examines the influence of climatic factors, such as wind, humidity, and precipitation on saltation activity and dust emissions from the Yellow House Basin.

PHYSICAL SETTING

The Southern High Plains, also known as the Llano Estacado, are a distinct physiographic region located at the southern end of the Great Plains (Fig. 1). It is best described as an immense plateau or tableland of approximately 78,000 km^2 bounded on three sides by "caprock" escarpments 50 to 200 m high (Reeves and Reeves, 1996). The western and northern escarpments separate the plateau from the Pecos and Canadian River valleys, respectively. Spring sapping and headward erosion by tributaries of the Red, Brazos, and Colorado Rivers have etched away at the eastern escarpment, which separates the Southern High Plains from the Rolling Plains of Texas and Oklahoma (Holliday, 1995). To the south, the plain passes without sharp physiographic break into the Edwards Plateau of central Texas.

Aeolian deposition on grassland vegetation formed the uppermost soils of the Southern High Plains (Gustavson and Holliday, 1999). Within the last century, however, most of the natural vegetation has been converted to an extensive patchwork of cropland. For example, cropland accounts for 80% of the total surface area within Lubbock County and cotton acreage accounts for 87% of harvested cropland (USDA-NASS, 1997). Each year, cotton fields pass through a regular cycle. Planting begins in May and is completed by mid-June. As cotton plants grow, they

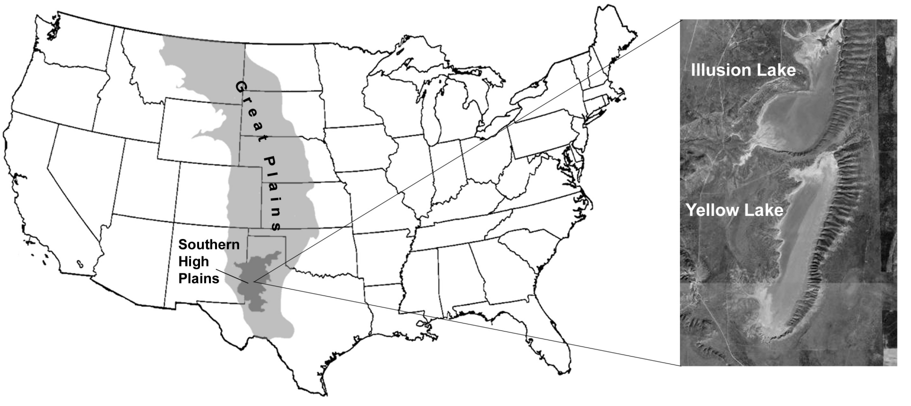

Fig. 1. Location of the Southern High Plains (dark gray) within the Great Plains (light gray). The Yellow House Basin, located near the geographical center of the Southern High Plains, contains two large saline playas called Illusion Lake and Yellow Lake.

Fig. 2. USGS aerial photograph of the Yellow House Ranch showing Yellow Lake and the fringing dunes that line the east side of the playa. The white dot marks the location of the acoustic water level sensor and the black dot marks the location of the meteorological tower and piezoelectric saltation sensor.

provide ground cover and wind erosion protection. Vegetative cover is removed during harvest, which takes place from October to December. After harvest, fields lie bare and exposed from late winter through spring when wind speed is at a

Fig. 3. The playa surface at Yellow Lake and the partially vegetated fringing dunes to the east.

maximum. This unfortunate combination of strong winds and bare fields has contributed significantly to the frequent dust storms that blow across this region (Laprade, 1957; Stout, 2001).

If all the cropland in the Southern High Plains was replanted to grass or otherwise stabilized there would remain a few natural dust sources that would continue to emit dust. In terms of surface area, the numerous saline playas are among the largest natural dust sources in this region. There are 21 large (>5 km^2) topographically closed basins spaced across the Southern High Plains that contain an estimated 40 saline playas (Reeves, 1966; Sabine and Holliday, 1995; Wood and Sanford, 1995; Holliday, 1997). Yellow House Basin is the third largest closed basin with a depression area of 74 km^2 (Reeves, 1966). It contains two saline playas—Yellow Lake and Illusion Lake (Fig. 1).

Yellow Lake (Fig. 2), the focus of this study, has a playa surface that is 4.4 km long by 1.0 km wide with a surface area of approximately 3.2 km^2. Partially vegetated clay dunes that extend to as high as 35 to 40 m above the playa surface border the east side of the playa (Fig. 3). Although the water table fluctuates seasonally, it remains near the surface even when the playa is dry. At times, surface waters form a broad shallow pool that occupies a limited fraction of the playa surface. Maximum surface water depth rarely exceeds 20 cm and is more often significantly less than this value. The location of the shallow pool has been observed to slowly move about the flat lakebed as it is pushed by the wind similar to the "roving lakes" described by Torgersen (1984). The portion of the playa surface not wetted by the shallow pool remains susceptible to aeolian deflation.

Fig. 4. The acoustic water level sensor. Water depth is determined by measuring the time it takes for a sound wave to bounce off the water surface and return to the sensor.

EXPERIMENT

Two sampling systems were installed on the playa surface at Yellow Lake. An acoustic water-level sensor (Fig. 4) was placed near the center of the playa to measure the depth of surface water and a 2-m tall meteorological tower was installed on the east side of the playa to record basic climate data (Fig. 5). The locations of the sampling systems are shown in Figure 2.

Wind speed was measured with a lightweight fast-responding cup anemometer and a wind vane both mounted at a height of 2 m. A tipping-bucket rain gauge with a resolution of 0.1 mm per tip was used to measure precipitation. A pyranometer, thermocouple, and capacitance-type RH sensor were used to measure solar radiation, air temperature, and relative humidity. Climate variables were sampled at a frequency of 1 Hz and at the end of each hour; values were either averaged or summed.

Aeolian activity was monitored with a piezoelectric saltation sensor (Fig. 6) located 10 m to the west of the meteorological tower. The cylindrical sensing element extended from 50 mm to a height of 63 mm above the playa surface and the diameter of the sensing element was 25 mm. During periods of active saltation, the piezoelectric transducer produced a signal that was used simply as an on-or-off indicator of saltation activity. Each pulse signal generated by each saltating grain that impacts the sensor was detected and if one or more impacts were detected during a given second then that second was registered as one "saltation second" or one second of saltation activity. At the end of each hour the total number of saltation seconds were summed and output to final storage.

Saltation activity is expressed as a dimensionless ratio of the total number of saltation seconds divided by the total number of seconds within the period of measurement. Thus, hourly saltation activity is simply the hourly total of saltation seconds divided by 3600 sec. Using these same data one can also calculate daily, monthly, seasonal or yearly saltation activity. In each case, saltation activity defines the fraction of time that aeolian activity was detected and, therefore, provides a measure of the frequency rather than the magnitude of sediment transport.

Fig. 5. The 2-m meteorological tower equipped with an anemometer, wind vane, pyranometer, relative humidity, and temperature sensors.

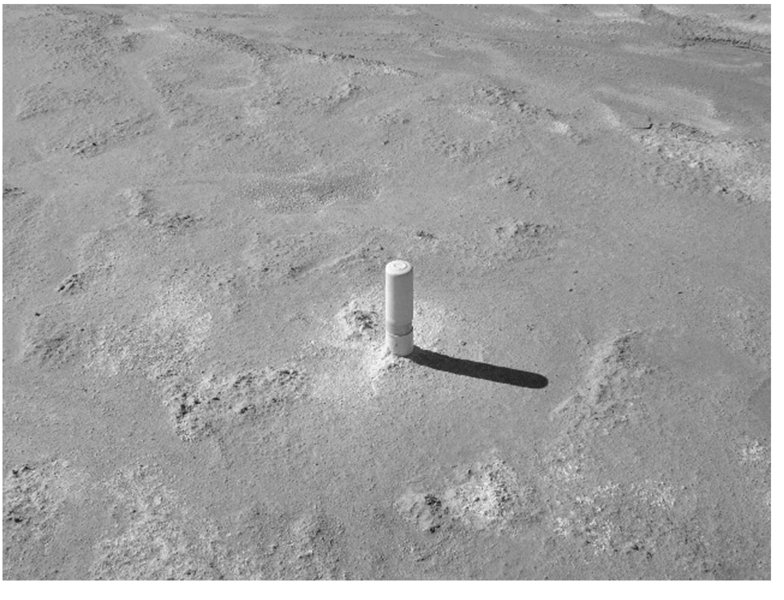

Fig. 6. The piezoelectric saltation sensor (SENSIT) extending from the playa surface at Yellow Lake.

Piezoelectric saltation sensors can occasionally produce false indications of blowing sand for various reasons. Precipitation can cause false readings when raindrops impact the sensor directly or when rain splashes a mixture of water and soil

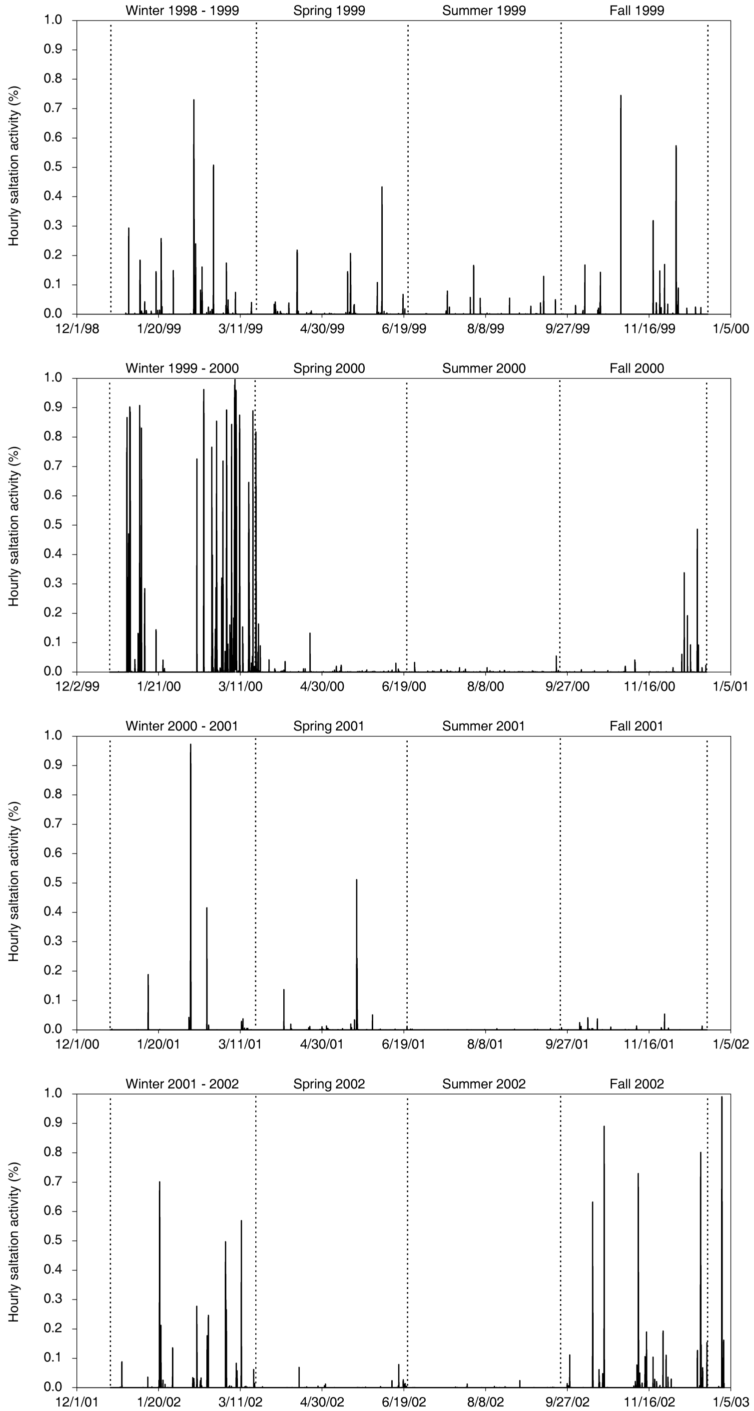

Fig. 7. Hourly saltation activity measured at Yellow Lake, separated by season and year.

particles onto the sensor. Less frequently, false indications can occur when animals or insects contact the sensor. In an attempt to limit false readings due to rain, saltation seconds were manually set to zero during periods of rainfall. Other false readings were detected by sorting the data set by maximum wind gust and a judgement was made as to whether saltation activity was possible given the maximum-recorded wind speed. Observations suggest that minimum threshold was typically from 6 to 10 m/s at Yellow Lake depending upon surface conditions. Saltation seconds were manually set to zero if the maximum wind gust remained well below threshold. Unfortunately, it was not always possible to distinguish between false readings and real blowing events when maximum wind speed was near threshold and, therefore, the final dataset may still contain a few false indications of blowing sand. Nevertheless, false indications are rare and the overall picture of saltation activity is not changed appreciably by their inclusion or elimination.

RESULTS

Measured hourly saltation activity values are plotted in Figure 7. A seasonal reference frame is provided across the top of each graph. These data provide a continuous record of aeolian activity at a point on the playa surface from December 30, 1998, to January 1, 2003.

Periods of aeolian activity, referred to as "blowing events," appear as intermittent peaks that extend outward with varying intensity. Blowing events can and do occur at any time of the year when conditions are favorable; however, the highly intermittent nature of the saltation record suggests that the necessary conditions for aeolian transport are rarely satisfied. For the 4-yr. period from1999 through 2002, 93% of the hours measured had no detectable saltation activity (an hourly saltation activity value of zero). Clearly, the saltation record contains many hours of inactivity punctuated with relatively brief periods of saltation activity.

During a few rare events, hourly saltation activity approached unity, indicating nearly continuous sediment transport over a one-hour period. The highest values of hourly saltation activity measured during this experiment are listed in Table 1. The highest value, .996, was recorded on March 7, 2000, at 1900 LST (Local Standard Time) and there were six other hours with saltation activity greater than .9 during this same winter day. Overall there have been a total of 20 values of hourly saltation activity greater than .9 from December 30, 1998 to January 1, 2003. Such high levels of saltation activity have not been reported previously. The highest value measured by Stout and Zobeck (1997) during previous experiments on eroding cropland was only .52 and this value corresponded to a 5-min. observation rather than a full hour.

It is interesting to note that the top 20 hourly values all occurred during the winter months of December, January, February, or March. The winter months of 2000 were especially active; 70% of the top 20 values occurred during January, February, and March of 2000. It is also interesting to note that all of the top 20 hourly values were recorded during daylight hours between 0900 and 1900 LST.

A visual inspection of Figure 7 reveals that there can be significant differences in the amount of saltation activity from one year to the next. An annual summary of

Table 1. Top 20 Values of Hourly Saltation Activity Measured at Yellow Lake from December 30, 1998, to January 1, 2003

Rank	Date and time	Hourly saltation activity	Rank	Date and time	Hourly saltation activity
1	03/07/00 19:00	.996	11	03/08/00 09:00	.959
2	03/07/00 18:00	.991	12	03/08/00 10:00	.952
3	12/30/02 15:00	.991	13	02/17/00 16:00	.939
4	12/30/02 14:00	.986	14	03/07/00 12:00	.938
5	12/30/02 16:00	.983	15	02/08/01 14:00	.934
6	03/07/00 13:00	.977	16	02/17/00 15:00	.915
7	03/07/00 15:00	.974	17	03/07/00 11:00	.914
8	02/08/01 15:00	.973	18	01/09/00 11:00	.908
9	03/07/00 17:00	.970	19	02/08/01 17:00	.906
10	02/17/00 17:00	.962	20	01/03/00 11:00	.903

Table 2. Annual Summary of Saltation Activity and Environmental Conditions at Yellow Lake

Year	Annual rainfall (mm)	Annual relative humidity (%)	Annual 2-m wind speed (m/s)	Annual saltation seconds (sec.)	Annual saltation activity
1999	494	56	3.8	77,230	.0024
2000	235	56	3.7	337,867	.0107
2001	297	62	3.3	35,334	.0011
2002	440	56	3.4	116,908	.0037

saltation activity and associated environmental conditions are provided in Table 2. These data suggest that saltation activity was at a low point in 2001 with only 35,334 saltation seconds or an annual saltation activity of .0011. Saltation activity for 1999 was approximately twice that of 2001 with 77,230 saltation seconds or an annual saltation activity value of .0024. A much larger total of 337,867 saltation seconds was recorded in 2000, which yields an annual saltation activity value of .0107; the only year with annual saltation activity greater than .01. The second largest total of 116,908 saltation seconds was recorded in 2002, with an annual saltation activity value of .0037. Overall, the results suggest that saltation activity rarely accounts for more than 1% of the total time within a year and it is most often significantly less than 1%.

Variations in saltation activity reflect changes in environmental conditions. Daily saltation activity is plotted along with important environmental factors such as daily wind speed, precipitation, relative humidity, and surface water depth in Figures 8 through 12. Daily saltation activity is calculated by summing all saltation seconds within a single day and then dividing by 86,400 sec. Results provide valuable

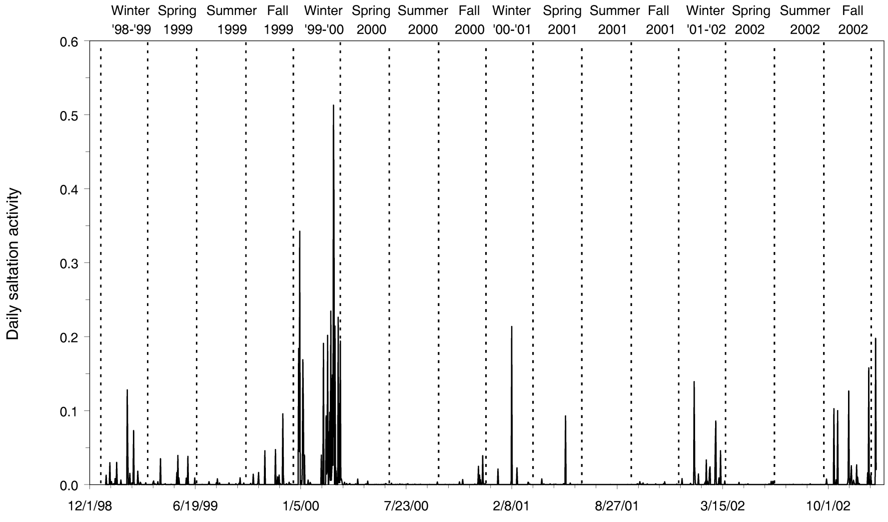

Fig. 8. Daily saltation activity measured at Yellow Lake plotted as a single time series that extends from December 30, 1998, to January 1, 2003.

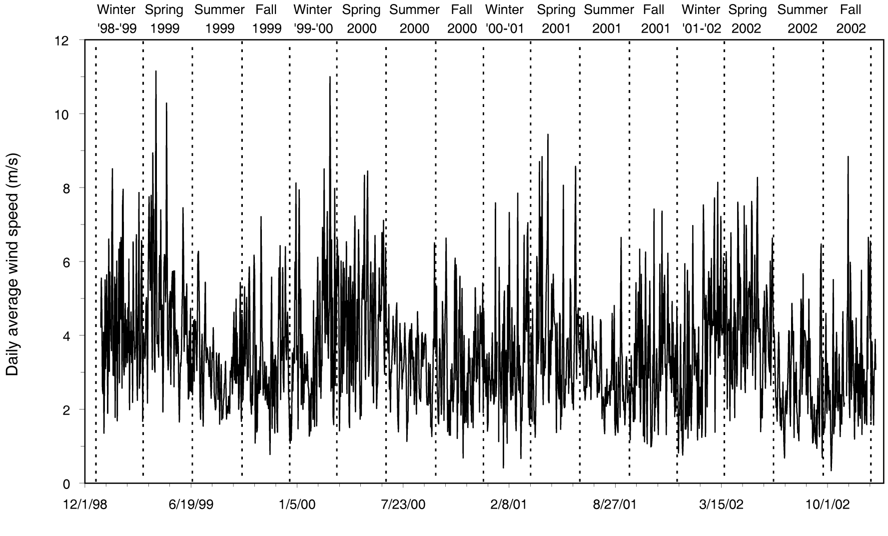

Fig. 9. Daily wind speed measured at Yellow Lake with a cup anemometer mounted at a height of 2 m.

information regarding temporal variations of aeolian activity and the associated microclimate from December 30, 1998, to January 1, 2003.

The overall seasonal pattern of saltation activity is not changed by changing the time scale from hourly to daily; however, daily saltation activity appears to more clearly define seasonal patterns of aeolian activity by emphasizing blowing events

Table 3. Top 20 Values of Daily Saltation Activity Measured at Yellow Lake from December 30, 1998, to January 1, 2003

Rank	Date	Daily saltation activity	Rank	Date	Daily saltation activity
1	03/07/00	.513	11	02/17/00	.191
2	03/08/00	.385	12	01/01/00	.184
3	01/03/00	.343	13	01/09/00	.169
4	03/02/00	.235	14	12/17/02	.158
5	03/16/00	.226	15	03/05/00	.148
6	03/10/00	.214	16	01/20/02	.139
7	02/08/01	.214	17	02/10/99	.128
8	02/25/00	.202	18	11/09/02	.127
9	12/30/02	.198	19	03/18/00	.109
10	03/20/00	.194	20	10/12/02	.103

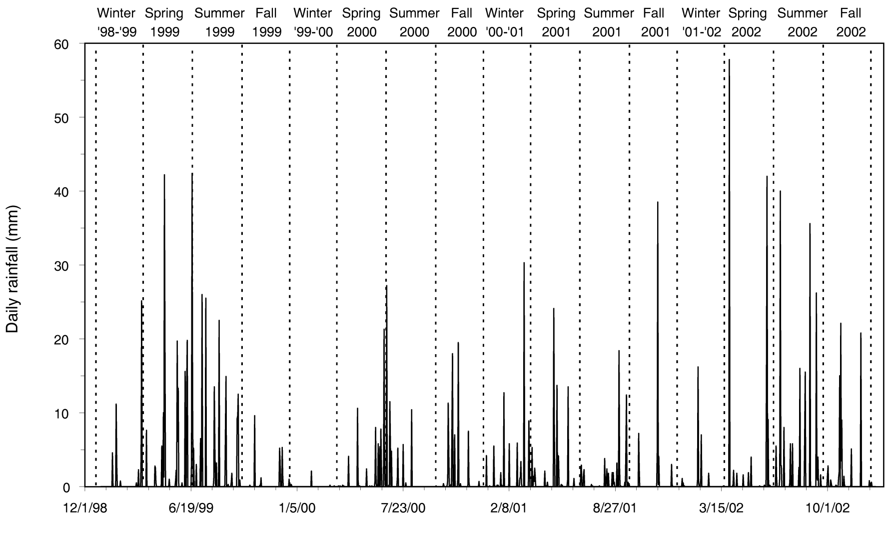

Fig. 10. Daily rainfall measured at Yellow Lake from December 30, 1998, to January 1, 2003.

that last for multiple hours. Values of daily saltation activity, plotted in Figure 8, are typically much lower than values of hourly saltation activity, plotted in Figure 7. Extreme values of hourly saltation activity occasionally approach unity whereas peak values of daily saltation activity rarely exceed .5. Twenty of the highest values of daily saltation activity recorded during this experiment are listed in Table 3. The highest value, .513, was recorded on March 7, 2000, and the second highest value .385 was recorded the next day. As one goes down the list, values of daily saltation activity drop off quickly to less than .1. From 1999 through 2002, only 1.5% of all

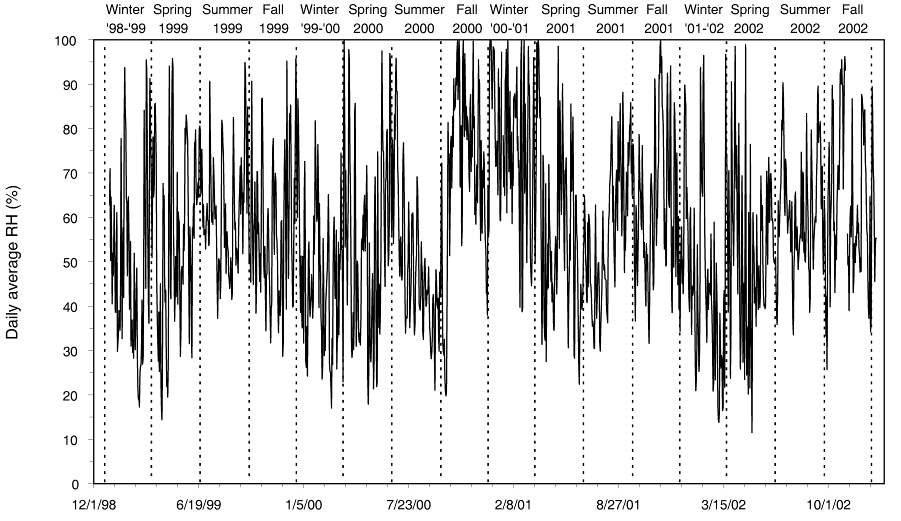

Fig. 11. Daily relative humidity measured at Yellow Lake from December 30, 1998, to January 1, 2003.

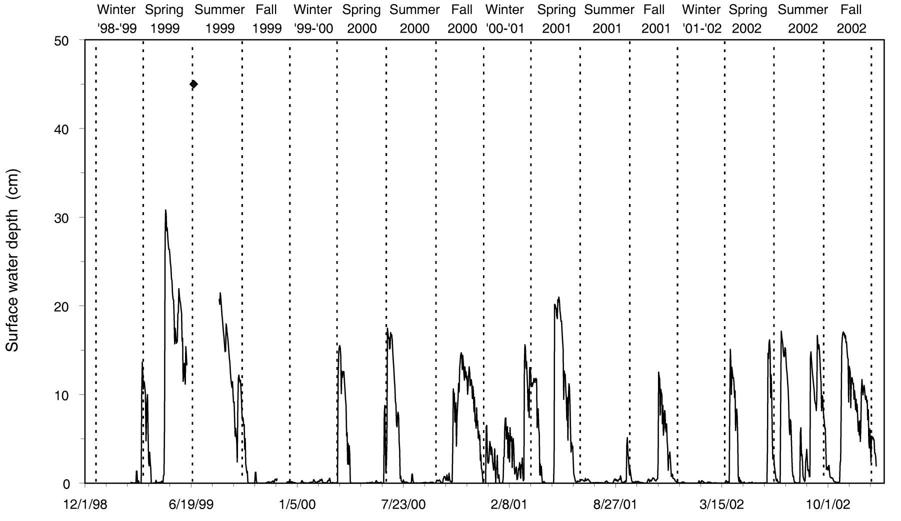

Fig. 12. Daily surface water depth measured at Yellow Lake from February 25, 1999, to January 1, 2003. The system malfunctioned from June 11, 1999, to August 11, 1999. The author manually measured a depth of 45 cm on June 24, 1999, and this value is plotted as a single point on the graph.

the days measured had daily saltation activity values greater than .1. Clearly, it is rare for saltation activity to account for more than 10% of any day.

Wind speed, plotted in Figure 9, appears to follow an annual cycle that typically peaks during the late winter and spring. Wind speed tends to be at a low point during summer and it is not surprising that there are generally low levels of saltation

Table 4. Seasonal Saltation Activity and Environmental Conditions at Yellow Lake

Season	Total rainfall (mm)	Average relative humidity (%)	Average water depth (cm)	Average wind speed (m/s)	Total saltation seconds (sec.)	Seasonal saltation activity
Winter 1998/1999	52	49	–	4.3	34,735	.00502
Spring 1999	186	55	13	4.6	15,415	.00192
Summer 1999	229	61	24	3.1	3,193	.00039
Fall 1999	28	57	1	3.4	23,899	.00308
Winter 1999/2000	3	48	0	3.8	306,663	.03988
Spring 2000	75	54	3	4.5	20,890	.00261
Summer 2000	72	50	3	3.2	1,208	.00015
Fall 2000	82	70	6	3.2	9,105	.00117
Winter 2000/2001	87	77	4	3.3	23,358	.00304
Spring 2001	85	57	7	3.9	9,618	.00120
Summer 2001	67	57	0	3.0	114	.00001
Fall 2001	61	63	2	3.2	1,551	.00020
Winter 2001/2002	30	45	0	3.7	41,520	.00540
Spring 2002	138	52	3	4.3	1,706	.00021
Summer 2002	185	61	6	2.7	259	.00003
Fall 2002	88	63	7	2.9	55,250	.00704

activity during the summer. Seasonal variations of rainfall, relative humidity, and surface water depth are less clearly defined in Figures 10, 11, and 12.

A seasonal summary of saltation activity and associated environmental conditions is presented in Table 4. Values of rainfall, relative humidity, surface water depth, and wind speed represent totals or averages taken over an entire season and seasonal saltation activity is defined as the sum of all saltation seconds recorded for a given season divided by the total number of seconds within that season. Results suggest that the playa surface is highly active during winter when humidity and precipitation are generally low and winds are moderately strong. Four of the top six values of seasonal saltation activity were recorded during the winter season. Winter 1999/2000 was especially active with a total of 306,663 saltation seconds or a seasonal saltation activity of nearly .04. This value is an order of magnitude larger than any other seasonal period and this intense saltation activity is clearly visible in Figure 8. Rainfall during this winter period was the lowest recorded for any seasonal period (only 3 mm) and this season had the second lowest seasonal average relative humidity. The lack of significant rainfall during winter 1999/2000 is clearly visible in Figure 10. Dry conditions were also evident in the lack of measurable surface water during this winter period, as shown in Figure 12. Heavy rainfall and high surface water depth during the previous spring and summer suggest that significant runoff may have contributed to substantial fluvial deposits that later provided plentiful source material for aeolian transport. Dry conditions with abundant loose erodible material generally indicate a playa surface with a low threshold condition.

Seasonal average wind speed was only moderately high during winter 1999/2000 due to a period of abnormally weak winds toward the middle of the season. Nevertheless, strong winds at the beginning and end of this winter period coupled with a low threshold condition contributed to exceptionally high saltation activity.

Seasonal saltation activity was relatively low during winter 2000/2001 compared to other winter periods with a seasonal saltation activity value of only .003. This value is more typical of the fall or spring season and is most likely a result of the unusually wet conditions and the unusually weak winter winds. In addition, winter 2000/2001 had the highest rainfall and the highest average water depth of any winter period measured and it had the highest average relative humidity of any other seasonal period. Moist conditions increase the critical threshold of the playa surface and this coupled with the relatively low average wind speed of 3.3 m/s resulted in a very inactive playa surface.

It is interesting to note that seasonal average wind speed is typically highest during spring, yet measurements indicate that saltation activity remains low. The primary reason is due to wet surface conditions produced by abundant spring rainfall. Rain moistens the playa surface and increases the threshold wind speed, which leads to low saltation activity. Saltation activity is still possible during the spring but only during occasional dry periods that happen to coincide with extreme wind events.

Saltation activity is often at a low point during the summer. Only 114 saltation seconds were recorded for the entire summer of 2001, which yields a seasonal saltation activity value of .00001. Seasonal saltation activity values as low as .00003, .00015 and .00039 were also recorded for summers 2002, 2000 and 1999, respectively. Average wind speed during summer is typically among the lowest of any season and this coupled with significant rainfall and high humidity contributes to low saltation activity during most summers.

CONCLUSION

Four years of continuous monitoring of aeolian activity have been completed on the saline playa called Yellow Lake. Results provide a detailed view of a highly dynamic aeolian system that responds quickly to changing environmental conditions. Results show periods of intense saltation activity associated with a combination of strong winds and dry conditions along with many inactive periods where no saltation activity was recorded due to rain or weak winds.

Overall, results suggest that saltation activity typically peaks during the winter despite the fact that winds are strongest during the spring season. A dry playa surface and moderately strong winds often combine to provide the necessary conditions for significant aeolian activity during the winter months. Spring rainfall and associated runoff often moistens the playa surface, which significantly increases threshold velocity, and essentially shuts down saltation activity despite strong winds.

It is well known that wind erosion on agricultural lands on the Southern High Plains typically peaks during the spring due to the combination of strong spring winds and an abundance of bare cropland (Wigner and Peterson, 1987; Lee et al., 1994; Stout, 2001). From 1999 through 2002, aeolian activity at Yellow Lake was out of phase with the normal annual cycle of agricultural wind erosion. Thus, when residents of the Southern High Plains were experiencing elevated dust levels during spring dust storms, saline playas, such as Yellow Lake, were contributing little to the atmospheric dust load.

Acknowledgments: I would like to thank James R. Golden for helping to design, construct, and maintain both sampling systems, and Thomas Albus and the Yellow House Ranch for allowing us to perform this experiment. I would also like to thank C. C. (Tex) Reeves and Jeffrey A. Lee for their careful reviews of this manuscript. I am also grateful to Vatche Tchakerian and an anonymous referee for their constructive advice and support.

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